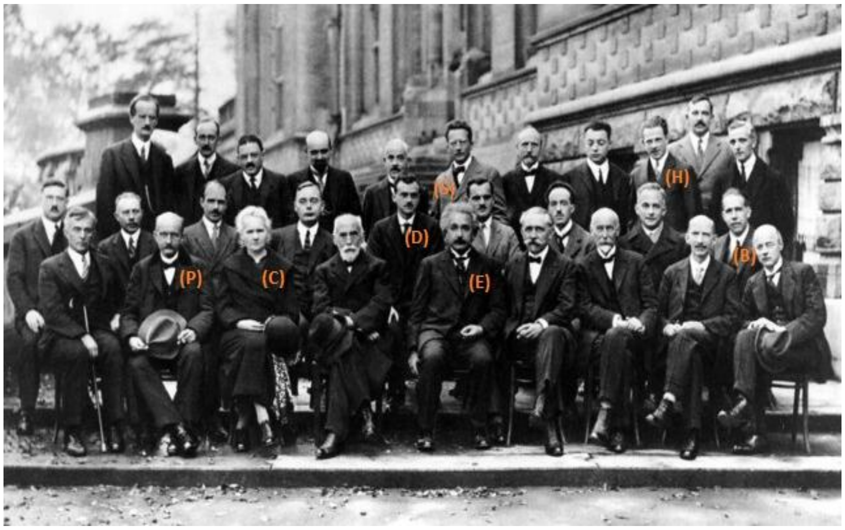
How Big Is a Particle?

The physics of the infinitely small aims to observe ever finer details in the structure of matter. Each step has revealed new objects, which physicists have been eager to study!

Participants in the 5th Solvay Conference in 1927

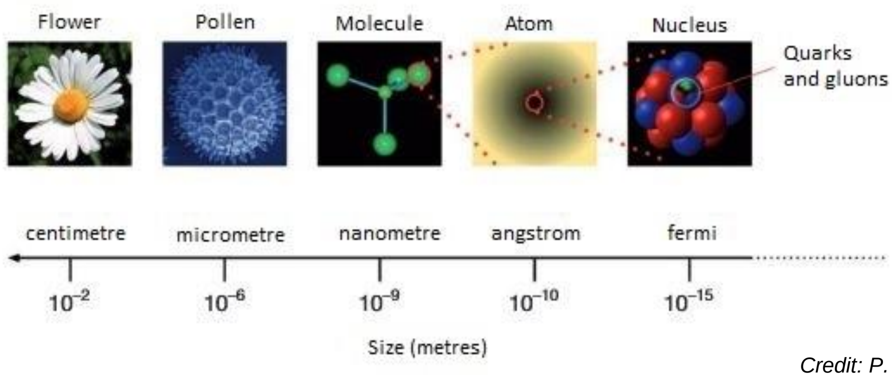
The theme of this edition of the Solvay Conference, named after its patron, the Belgian industrialist Ernest Solvay, was 'electrons and photons'. The event marked the acceptance of quantum mechanics – which greatly differs from so-called 'classical' physics – by the scientific community. One special feature of this conference was that 17 out of the 29 participants had won or would win a Nobel Prize! Amongst them, Niels Bohr (B), Marie Curie (C), Paul Dirac (D), Albert Einstein (E), Werner Heisenberg (H), Max Planck (P), Erwin Schrödinger (S)...



Wikipedia

Physicists spend their time reasoning in terms of orders of magnitude: what is the typical speed of a car? the usual size of a grain of sand? the distance between two planets in the solar system?

Indeed, to modelise a phenomenon, you need to identify the relevant elements and describe them using the appropriate tools, while dismissing what is too small, too big, too slow, or too fast. For instance, to study the trajectory of a car on a race track, it is useless to look at the Earth's rotation around the Sun (distance and time scales are far too large) or at the movement of dust grains in the glove compartment (distance and time scales are far too small). And there's no need to resort to quantum mechanics or general relativity to determine whether the car will slide off the road at the next curve!



Credit: P. Royole-Degieux, from A. Drouart

To understand the distances associated with the infinitely small, let's start with us, humans. Our typical size is of the order of a metre – yes, that's how physicists see us, whether we are 1.60 m or 2 m tall... Each of our cells is a million times smaller, and if you zoom in a hundred times (a hundred millionth meter), you can make out the DNA at the heart of their nuclei.

Zoom in another ten times and you will reach a billionth metre: that's the distance between two atoms in a molecule. Atoms themselves are ten times smaller. They are formed by electrons and an atomic nucleus whose size is ten thousand times smaller (a hundred thousandth billionth metre), made up of protons and neutrons that are themselves ten times smaller. That's a millionth millionth millimetre.

Let's delve even deeper into matter. Neutrons and protons are made up of quarks of an unknown size (at least a thousand times smaller than protons). We don't know the size of electrons either. So far, experiments seem to indicate that quarks and electrons are point-like and, therefore, elementary particles... Are they really? Or is the resolution of our experiments still too low to reveal their structures? No one knows.

Each level of detail has its own scientific field: materials physics, chemistry, atomic physics, nuclear physics, particle physics, etc. All these scales of distance have a counterpart in terms of energy. The more we want to probe matter over short distances, the more energy is needed for the projectiles, and the larger the accelerators. That's why particle physicists, in their race to the infinitely small, have also embarked in ever larger experiments – right up to the LHC, whose detectors are the size of multi-storey buildings.

From a flower to quarks: towards the infinitely small

To each length scale correspond new details that provide additional information on the structure of matter. Below the nanometre, figures are representations, not actual photographs. The physics of the infinitely small explores a broad field currently ranging from the angstrom (a tenth billionth metre, i.e. the characteristic size of an atom) to a billionth billionth metre. Smaller scales still elude experimentation and their possible content remains a mystery.

Translated from 'Une particule, c'est gros comment ?', **Passeport pour les deux infinis,** ***IN2P3/Dunod, https://pass2i.ijclab.in2p3.fr/ (French); updated with ICHEP2024 conference (https://ichep2024.org) for IPPOG***